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Effects of Nursery Fertilizer and Irrigation on Ponderosa and Lodgepole Pine Seedling Size

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Abstract—Eight fertilizer treatments combined with three irrigation regimes were used when growing lodgepole and ponderosa pine seedlings on two soil types at Lucky Peak Nursery near Boise, ID. Seedlings of both species were larger on the sandy loam than the clay loam soil. Milorganite, an organic fertilizer derived from sewage sludge, reduced initial seedbed densities but had no further effects. Ammonium nitrate increased seedling size on the clay loam, but not on the sandy loam soil. Increased irrigation was more effective in increasing seedling size on the sandy loam than on the clay loam soil. However, ponderosa pine receiving the least irrigation in the nursery grew the fastest for 3 years after being transplanted in the field, possibly because of drought conditioning.

Keywords: nursery operation, cultural methods, soil texture, sewage sludge, forest nurseries, *Pinus ponderosa, Pinus contorta,* Idaho

Production of bareroot tree seedlings is no easy job. Stock must be vigorous and ready to grow when planted and must be large enough to compete with other vegetation. Yet the seedlings should be small enough to facilitate easy planting and their size should be consistent. We know that seedling quality and size are influenced by nurseries' cultural practices, but we need more precise information on the effects of changes in fertilization and irrigation. The ultimate goal is to determine the optimum combination of fertilizer, irrigation, and seedling density to produce the best possible seedlings with the greatest efficiency.

The relationship between the effects of moisture, nutrients, and light on seedling morphology and physiology is complicated. As levels of these resources are increased, the resource that makes the most difference is the one most limiting growth or other physiological activities. For instance, when the available nitrogen level in the soil is limiting seedling growth, additional water will not greatly increase size. Increasing the limiting resource may change the effects of increasing another resource.

Equally important, the size of seedlings affects their survival and growth after they have been transplanted in the field. Then, seedlings must compete for moisture, nutrients, and light with shrubs, forbs, and grasses. On dry planting sites, like those found in the Intermountain West, excessively large seedling shoots aren't likely to be successful unless their root systems are large enough to support them. Small seedlings, however, have difficulty competing with other well-established vegetation.

In this study we looked at the effects of eight different fertilizer treatments and three irrigation regimes on the density, size, and field performance of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) produced at Lucky Peak Nursery near Boise, ID.

METHODS

The study was established in the spring of 1983 in seedbeds on sandy loam and clay loam soils. In March 1982, a 1-inch (2.5-cm) layer of sawdust and 400 pounds per acre (448 kg/ha) of ammonium nitrate (34-0-0) were incorporated into the soil before sowing a cover crop of Austrian peas. The peas were plowed under in late July. The soil was fumigated with a mixture of methyl bromide and chloropicrin in September. Ponderosa pine and lodgepole pine seed were sown into adjacent beds on both soils in April 1983.

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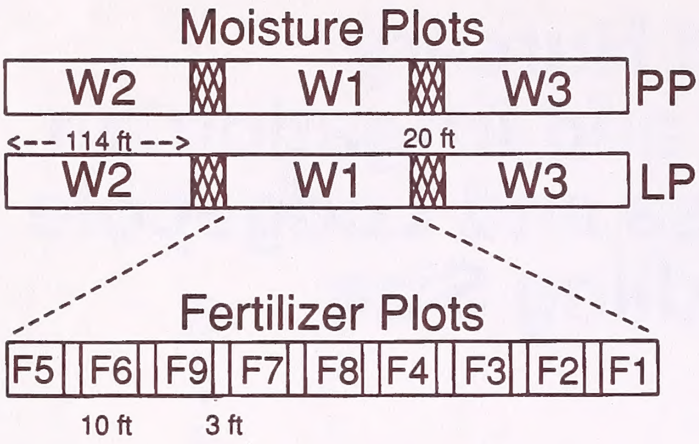

Figure 1—The plots in the nursery were set up in a split plot design. This diagram depicts the two nursery beds on the sandy loam soil, one with ponderosa pine (PP) and one with lodgepole pine (LP). The three irrigation regimes, moist (W1), medium (W2), and dry (W3), were arranged randomly as were the fertilizer plots within each moisture plot. See table 1 for explanation of the fertilizer treatments, F1-F9.

Each nursery bed was divided into three irrigation plots. Each irrigation plot was subdivided into nine fertilizer plots. The arrangement of the beds is diagramed in figure 1.

Table 1 compares the fertilizer treatments. Four of the treatments incorporated milorganite (6-2-0), an organic fertilizer derived from sewage sludge, before seeds were sown. Four fertilizer treatments incorporated ammonium nitrate (34-0-0) before seeds were sown. Four treatments incorporated treble superphosphate (0-46-0) before seeds were sown. All eight of these treatments were fertilized with either a 1x or 2x concentration (88 or 176 lb/acre, 98.64 or 197.29 kg/ha) of ammonium nitrate as a top dressing during mid-June of the first year (1983), early March of the second year (1984), and mid-June of the second year. One plot was a no-treatment control that received no fertilizer other than that added with the sawdust and cover crop amendments used on all plots.

Table 1—Plot densities resulting from various fertilizer treatments on ponderosa and lodgepole pine seedlings. Fertilizer treatments were: 1x milorganite = 1,000 lb/acre; 2x milorganite = 2,000 lb/acre; 1x nitrogen = 88 lb/acre ammonium nitrate; 2x nitrogen = 176 lb/acre ammonium nitrate; x phosphorus = 60 lb/acre treble superphosphate. For each mean within a column, ** indicates a significant difference from the control mean (*p* = 0.01) and * indicates a significant difference from the control treatment when *p* = 0.05 using the Single Degree of Freedom Method (Freese 1967)

Fertilizer treatment	Pre-sow milorganite	Pre-sow nitrogen	Pre-sow phosphorus	Top dressing nitrogen	Density (trees/ft²)		Average
					Sandy loam soil	Clay loam soil	
Ponderosa pine							
F1	1x			1x	26.1*	6.7	20.3
F2	2x			2x	15.4**	12.2	13.7
F3		1x		1x	33.8	9.9	18.0
F4		2x		2x	33.6	7.0	20.2
F5	1x		x	1x	25.0*	14.6	19.8
F6	2x		x	2x	23.3**	8.5	15.9
F7		1x	x	1x	31.6	10.4	21.0
F8		2x	x	2x	31.5	11.6	21.6
F9 (control)					38.6	11.7	25.1
Lodgepole pine							
F1	1x			1x	20.2	45.5	32.8
F2	2x			2x	14.5**	40.0	27.2
F3		1x		1x	25.8	52.2	39.0
F4		2x		2x	27.7	51.2	39.5
F5	1x		x	1x	21.5	45.5	33.5
F6	2x		x	2x	11.2**	36.7*	24.0
F7		1x	x	1x	29.9	50.9	40.4
F8		2x	x	2x	27.8	49.4	38.6
F9 (control)					30.3	47.8	39.0

Irrigation regimes were set up during the summer of the second year:

Moist regime—early morning plant moisture potential was not allowed to fall below –0.5 MPa (MegaPascal of moisture potential) for the entire growing season.

Medium regime—early morning plant moisture potential was not allowed to fall below –1.0 MPa between July 15 and September 1, and not below –0.5 MPa before July 15 and between September 1 and the end of the irrigation season.

Dry regime—early morning plant moisture potential was not allowed to fall below –1.5 MPa from July 15 to September 1, and not below –0.5 MPa before July 15 and between September 1 and the end of the irrigation season.

In other words, all plots were treated the same except during a 6-week period in midsummer when three levels of moisture potential were maintained: >–0.5 MPa, >–1.0 MPa, and >–1.5 MPa. The irrigation regimes were imposed only during the second growing season because frequent, light irrigation is required during the first year to prevent surface temperatures from rising to destructive levels. Plant moisture potential was monitored before dawn with a pressure bomb apparatus to determine when irrigation was necessary.

All fertilizer and irrigation treatments were arranged randomly in a split plot design. Each fertilizer plot took 10 feet (3.05 m) of nursery bed. Three-foot (0.91-m) buffers separated fertilizer plots. Twenty-foot (6.10-m) buffers separated irrigation regime plots.

Plants from six 1-foot (0.30-m) sections of each plot were lifted on March 18, 1985. Mean seedling density measurements came from these sections. Seedling height and caliper diameter measurements were made on 15 seedlings randomly selected from these sections. Seedlings were stored at 35 °F (3 °C) before being transplanted.

Ponderosa pine seedlings were planted on an appropriate site (Cascade District, Boise National Forest, elevation 5,400 feet, 1,646 m) in the *Pseudotsuga menziesii/Physocarpus malvaceus* habitat type (PSME/PHMA, Douglas-fir/ninebark) on May 11, 1985. The lodgepole pine was planted on an appropriate site (Ashton District, Targhee National Forest, elevation 6,500 feet, 1,981 m) in the *Pseudotsuga menziesii/Calamagrostis rubescens* (PSME/CARU, Douglas-fir/pinegrass) habitat type on May 16, 1985.

All planting spots were prepared by hand. Spacing was 6 feet (0.61 m) within and between rows from center to center of 2-foot square (0.18-m^2) scalps. Seedlings were planted in rows of 10. All trees in a row came from the same treatment. Three blocks contained complete sets of all treatment rows, randomly arranged. Lodgepole seedlings from the sandy loam and clay loam soils were planted. Because so few ponderosa pine seedling survived on clay loam soil, they were larger than they would have been otherwise. To prevent biasing the results of field growth studies, only ponderosa pine seedlings from the sandy loam soil were planted. We followed Forest Service recommended procedures for stock handling and planting in the Intermountain Region. All study treatments were handled uniformly.

RESULTS AND DISCUSSION

Most fertilizer treatments did not reduce seedbed densities (table 1). The exception was when milorganite was incorporated in the seedbed before sowing. Mortality was especially apparent on the sandy-loam soil. Seedling densities on the clay loam soil were more variable than on the sandy loam, especially between species (fig. 2).

In most cases, the 1x application (1,000 lb/acre, 1,121 kg/ha) of milorganite reduced the mean density of trees compared to control plots. Sometimes, however, the differences were not statistically significant ($p = 0.05$ using the Single Degree of Freedom Method, Freese 1967). The 2x applications (2,000 lb/acre, 2,242 kg/ha) significantly reduced seedling density on the sandy loam soil.

Because the effects of fertilizer treatments on seedling density varied so greatly on the clay loam soil, only one treatment was significantly different from the control. The variability was especially apparent in the ponderosa pine plot.

Lutrick and others (1986) report that addition of liquid, digested sewage sludge damaged or killed planted slash pine seedlings. Chang and others (1984) found 90 percent of the heavy metals sewage sludge deposited in the soil was in the top 6 inches (15 cm), but Comerford and Fiskell (1983) found that tissue accumulation of chromium, copper, cadmium, nickel, and zinc was not appreciable during the first year in a slash pine plantation on an acid sandy soil fertilized with industrial sewage sludge. Patterson and Olson (1983) showed that copper, nickel, and cobalt significantly reduced early elongation of embryonic roots (radicles) in three different pine species. Seed germination was unaffected by heavy metal concentrations up to 100 parts per million.

We did not measure heavy metal concentrations. Milorganite's reduction of seedling density apparently was not due to heavy metal toxicity because surviving seedlings seemed unaffected. After early mortality, seedling densities appeared stable. Milorganite may have enhanced fungal growth, increasing damping-off, a fungal disease that

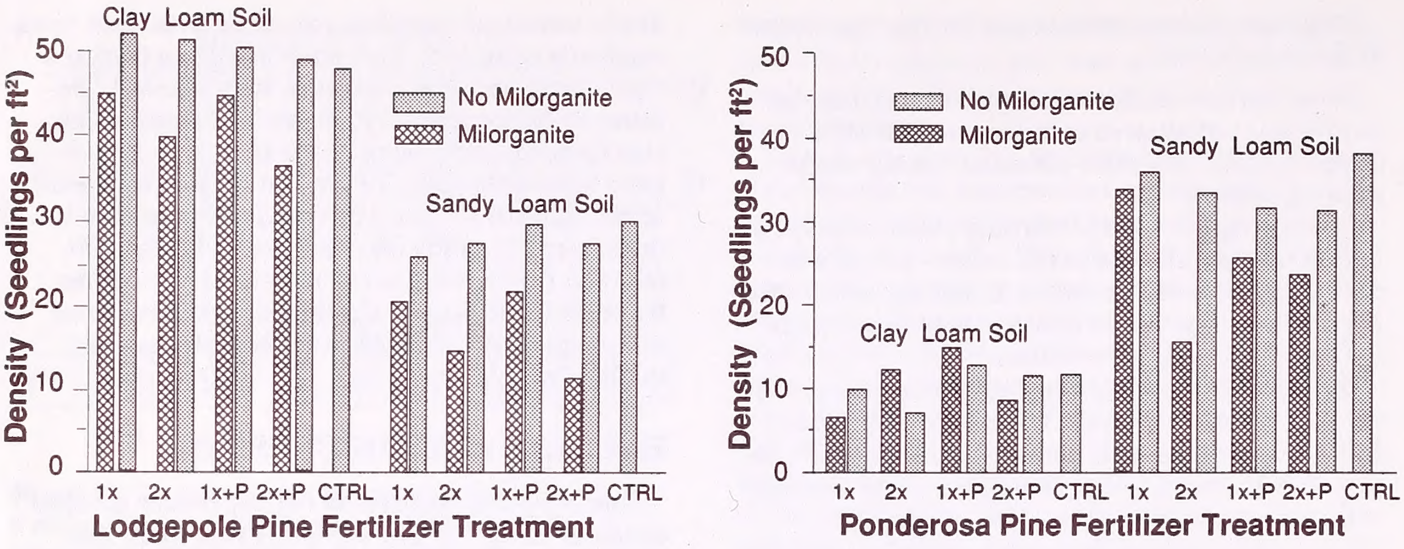

Figure 2—Comparison of mean seedling density (trees/ft²) for plots receiving a treatment of milorganite before sowing and those on which milorganite was not applied. Treatment codes represent milorganite concentrations and other fertilizer applications:

1x :	1,000 lb/acre milorganite or 88 lb/acre ammonium nitrate incorporated before sowing, plus an 88 lb/acre ammonium nitrate top dressing three times.
2x :	2,000 lb/acre milorganite or 176 lb/acre ammonium nitrate incorporated before sowing, plus a 176 lb/acre ammonium nitrate top dressing three times.
P:	60 lb/acre of treble superphosphate incorporated before sowing.
CTRL:	Control, no fertilizer.

sometimes kills seedlings. Patterson and Olson (1983) observed that in the presence of heavy metals, fungal growth occasionally appeared to block seedlings from developing after their seed coats split.

Neither nitrogen or phosphorus applied before sowing nor the top dressing of nitrogen applied after sowing lowered seedling densities like milorganite. In no case was there a statistically significant difference between the control treatment and fertilizer treatments F3 (1x nitrogen), F4 (2x nitrogen), F7 (1x nitrogen plus phosphorus), or F8 (2x nitrogen plus phosphorus) (table 1). However, there was a consistent visual difference between these fertilizer treatments and the denser ponderosa pine control plots on sandy loam soil.

Ponderosa pine seedling densities were so low on the clay soil that most information on seedling size was of little value (table 1). As spacing increased, so did the size of pine seedlings. Ponderosa pine seedlings on the clay soil were much larger than other seedlings in the study. Therefore, I did not include the ponderosa pine plots on the clay loam soil in the statistical analysis of seedling size. I dropped the milorganite treatments for both ponderosa and lodgepole pine from the size analysis because the lower seedling densities in these plots would confound conclusions about the effects of fertilizer and irrigation on seedling size.

Fertilizer applications did not increase seedling height or caliper on the sandy loam soil. At this seedling density, the fertility of the sandy soil was not a limiting factor, at least for nitrogen and phosphorus. On the clay loam soil nearby, both the 1x and 2x applications of nitrogen fertilizer seemed to increase the seedling mean heights and mean calipers, indicating a lack of available nitrogen. Phosphorous fertilizer did not appear to increase seedling growth on either soil (table 2).

Keeping the plant moisture potential of the lodgepole seedlings above –0.5 MPa (moist treatment) significantly increased the height and caliper of the lodgepole seedlings on the sandy loam soil. Keeping the plant moisture potential above –1.0 MPa (medium treatment) increased seedling heights, but not calipers, over the dry treatment (>–1.5 MPa, table 2).

Table 2—Lodgepole pine seedling sizes resulting from three irrigation regimes and four fertilizer treatments on two nursery bed soil textures. For each group of means, the means followed by the same letter are not significantly different (*p* = 0.05) using the Newman-Keuls test (Snedecor and Cochran 1978).

1xN = 88 lb/acre ammonium nitrate incorporated before sowing and added three times as top dressing.
2xN = 176 lb/acre ammonium nitrate incorporated before sowing and added three times as top dressing.
P = 60 lb/acre treble superphosphate incorproated before sowing

	Sandy loam		Clay loam		Average for both soils	
Treatment	**Height**	**Caliper**	**Height**	**Caliper**	**Height**	**Caliper**
	cm	*mm*	*cm*	*mm*	*cm*	*mm*
Water						
Moist (>–0.5 MPa)	18.3b	4.29b	13.0a	3.29a	15.6	3.79
Medium (>–1.0 MPa)	17.5b	3.78a	12.5a	3.18a	15.0	3.48
Dry (>–1.5 MPa)	16.7a	3.77a	11.9a	3.12a	14.3	3.45
Fertilizer						
F3 (1xN)	17.4a	3.98a	12.7b	3.17b	15.0	3.57
F4 (2xN)	18.1a	4.13a	13.7b	3.37bc	15.9	3.75
F7 (1xN+P)	17.0a	3.89a	12.5b	3.13b	14.7	3.51
F8 (2xN+P)	17.1a	3.94a	13.9b	3.49c	15.5	3.72
F9 (control)	17.9a	3.81a	9.5a	2.81a	13.7	3.31

Although the size trends were similar for lodgepole pine on the clay loam soil, the differences were not significant for heights or calipers. This was probably because the clay loam soil was more effective in holding moisture than the sandy loam soil. The seedlings on the clay loam took longer to reach the threshold moisture potentials. Then the clay loam required more irrigation to recharge. The sandy loam soil often gave up its available moisture very quickly, subjecting the seedlings to growth-limiting moisture stress before the next irrigation.

It is not possible to interpret the ponderosa pine size data from the clay loam soil because differences in seedling density confounded the results.

Third-year field survival of the lodgepole pine seedlings showed no relationship to seedling density in the nursery bed, seedling height, seedling caliper, fertilizer treatment, or irrigation treatment. Survival was very good across the board, averaging 99 percent. Proper planting techniques and favorable weather during the first growing season were a big part of the plantation success. After three growing seasons, we can still see seedling height differences caused by the nursery treatments. However, after outplanting (transplanting the seedlings in the field), we saw no more effects of the nursery treatments. This was demonstrated by the minimal difference in mean seedling growth between the fertilizer, water, and soil treatments (fig. 3). Seedlings from the two soil treatments have maintained their initial size differences. During all 3 years of field testing, there was no difference in seedling mean height growth. These findings are similar to those from a study on lodgepole pine by Baer and others (1977).

Likewise, for ponderosa pine, the fertilizer treatments did not significantly affect field growth (fig. 4). The summer of 1985 was very dry on the ponderosa pine planting site. That translated into poor growth. Seedlings from the medium moisture treatment (W2) were shorter when transplanted than seedlings from the other moisture treatments because more seedlings shared the space in the nursery bed (higher seedling density). The dry treatment (W3) seedlings grew more in the field on the average, possibly because of moisture stress conditioning in the nursery. Since seedling growth often reflects the previous season's photosynthesis, the second year's growth reveals what happened during the first year after transplanting. Seedlings from the moist treatment (W1) grew very little in the second field season, indicating stress during the first summer. Moisture stress conditioning may have been especially important because of the droughty weather that summer. After three growing seasons in the field, the mean seedling height was largest for the dry treatment (W3).

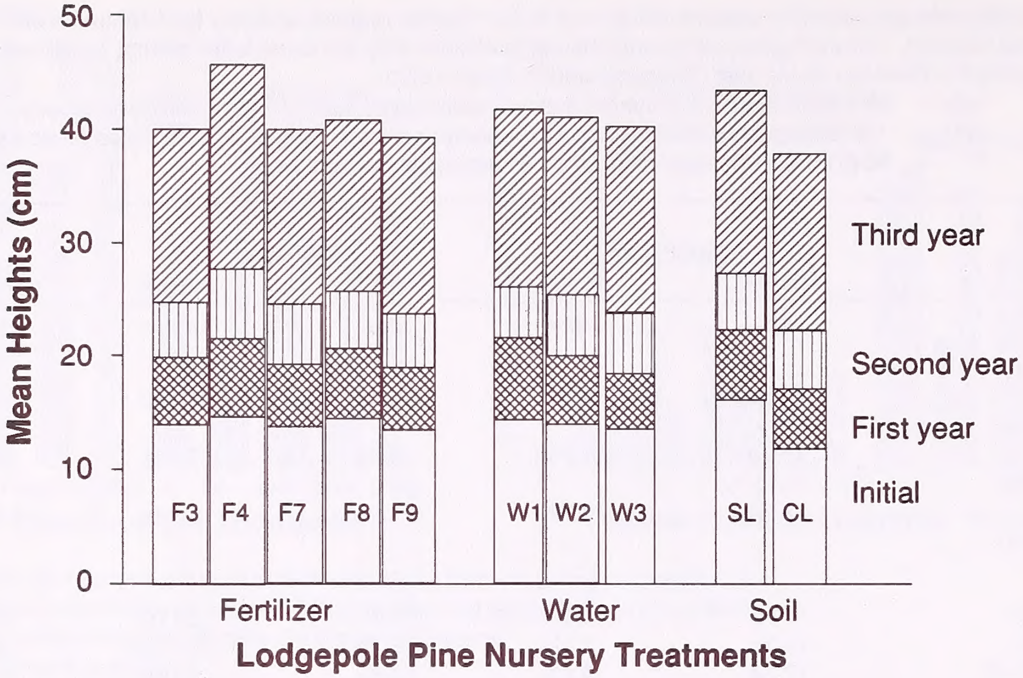

Figure 3—First-, second-, and third-year lodgepole pine seedling average heights for four fertilizer treatments F3, F4, F7, and F8 (see table 1 for detailed descriptions) and control (F9); three irrigation regimes: moist (W1), medium (W2), and dry (W3); and two soils: sandy loam (SL) and clay loam (CL).

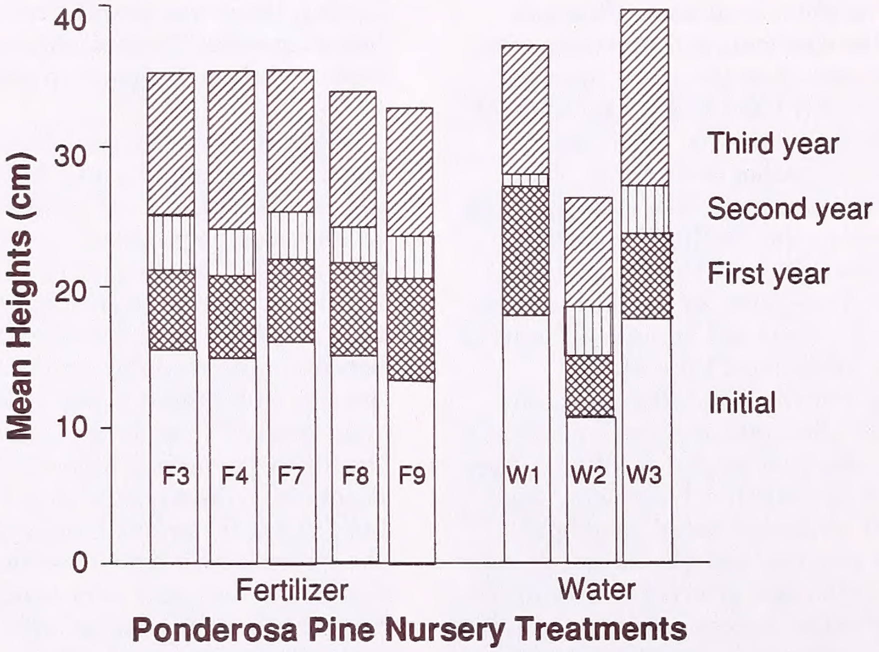

Figure 4—First-, second-, and third-year ponderosa pine seedling average heights for four fertilizer treatments F3, F4, F7, and F8 (see table 1 for detailed descriptions) and control (F9), and three irrigation regimes: moist (W1), medium (W2), and dry (W3).

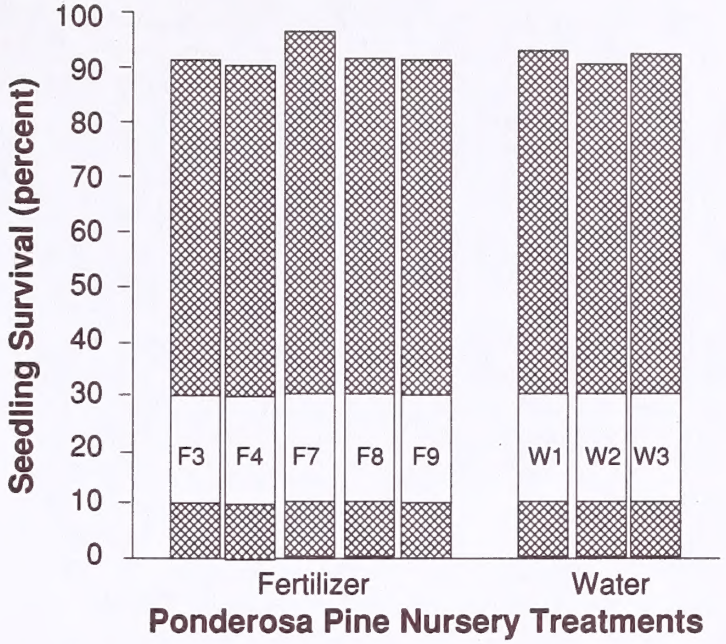

Figure 5—First-yearaverage survival of ponderosa pine seedlings for four fertilizer treatments F3, F4, F7, and F8 (see table 1 for detailed descriptions) and control (F9), and three irrigation regimes: moist (W1), medium (W2), and dry (W3).

Moisture stress did not show up in the first-year survival measurements (fig. 5). There is very little difference in survival among the different fertilizer or moisture treatments. The survival rate for all treatments was around 90 percent 1 year after transplanting in the field.

Shirley and Meuli (1939) found that for red pine, increasing nitrogen levels over a no-nitrogen control consistently decreased the ability of seedlings to resist drought. Likewise, drought resistance decreased when loblolly pine seedlings were supplied with more nitrogen than optimum (Pharis and Kramer 1964). Landis (1985) states that seedling nutrient status is more closely related to growth after outplanting than to initial survival, because an ample mineral nutrient supply does not guarantee a seedling the vigor it needs to survive transplanting and early moisture stress. I did not find increased fertilization in the nursery to improve survival or growth of either species. Benzian and others (1974) also found that uptake of nitrogen fertilizer by lodgepole seedlings in the nursery did not increase height growth significantly after outplanting. My lodgepole results agree with Benzian's.

CONCLUSIONS

The effects of irrigation and fertilization in the nursery bed at Lucky Peak Nursery differed between lodgepole and ponderosa pine. Also the effects were different on two different soil types a short distance from one another.

Although milorganite reduced first-year seedling density in the nursery bed, especially for ponderosa pine, we found no direct effects in the second year or beyond. The exception is the secondary increase in seedling size due to the decreased and less consistent seedling densities. Lower density generally produced larger seedlings, but seedlings that were more variable in size.

Both species grew well on the sandy soil, but the lodgepole pine seedlings handled the heavy clay soil better than the ponderosa pine seedlings. Lodgepole pine seedlings were larger on the sandy-loam soil than on the clay loam soil. Phosphorus was not limiting in either soil, but nitrogen fertilizer increased lodgepole seedling size on the clay-loam soil. Increased moisture stress (less irrigation) reduced lodgepole seedling size on the sandy-loam soil.

Fertilizer treatments had very little effect on field growth or survival of lodgepole and ponderosa pine after three growing seasons. Nursery moisture did not influence survival of either species. However, the dry moisture treatment may have increased ponderosa pine seedling growth in the field by conditioning them to moisture stress.

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